E-du Box: Educational Multimedia with Tangible-Enhanced Interaction

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ABSTRACT
Media resources usage has significant impact on children literacy in the first school years in Brazil [5]. Computer software and tangible interfaces can help engage pupils in effective learning activities. Tangible interfaces built with familiar objects of our everyday lives such as wood and tissues are well accepted by pupils. In this work, we detail our design and evaluation of e-du box – an educational, authoring and sharing multimedia platform including a tangible companion that provides feedback for users. We employed a participatory design process based on providing supports intended to help children engage in different tasks. We could elicit a list of design guidelines for this specific application. We discuss our experience with this design approach and explore its implications.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation (e.g., HCI)]: User Interfaces. H. 5. 1 [Multimedia Information Systems]

General Terms
Design, Human Factors.

Keywords
literacy, tangible interaction, educational software, participatory design, social technology

1. INTRODUCTION
Literacy is a process that promotes socialization, since it establishes new types of symbolical exchanges among individuals, access to cultural assets and facilities offered by social institutions. It is also a key to the concept of citizenship and to society development in general, as well as is strongly related to health, better income and, therefore, life quality.

Recent studies from UNESCO, however, present some alarming facts related to literacy: more than one fifth of the worldwide population is illiterate. Over 771 million people (15 years old or more) are unprovided of basic reading, writing and calculation skills [4]. In Central Africa, for example, there is an impressive illiteracy rate of 80%. Brazil, the country where the first prototypes of the product presented in this work have been developed and tested, is not an exception. It is one of the 12 countries where three quarters of the illiterate adults live. More than 15 million Brazilians are not able to read what is written in their own national flag. If definitions such as functional, digital and social illiteracy are taken into account, the results are even worse [19].

In order to use the potential of technology to revert such statistics, some companies, universities and non-profit organizations are developing projects to create low-cost computers for educational purposes [12]. One characteristic shared among those projects is the fact that they are just simplified versions of regular personal computers, still keeping their appearance and user interface, while carrying with them some of the costs of full-sized computer’s solutions.
Furthermore, research with educators, pedagogues, students and other stakeholders revealed additional limitations and restrictions of current literacy approaches, including: the lack of possibilities for educators to customize learning content according to each student context, preferences and difficulties; a high dependency level of the learning process on classrooms and the presence of educators; the absence of a deep parental involvement in the learning process; the bureaucratic and non-automated way in which students’ progress is assessed; the lack of incentives to make content created by different educators around the world to be easily published and shared and, finally, the sub-exploration of technology to provide a real intuitive and usable interface, which makes digital approaches to be seen as complex and hard to use.

Taking such issues into account, we present the e-du box, a low-cost and flexible hardware/software edutainment platform, conceived with focus on literacy. It empowers educators with the necessary elements to provide rich (yet localized) multimedia content to students. The solution allows learners to experience content created by their own educator in an intuitive and stimulating way. E-du box provides a rich multimedia experience, enhanced by tangible interaction. The main input device is a special pen-shaped mouse that vibrates according to some situations defined by the educator. Feedback is also provided by a tangible, interactive and animated e-du agent, who is able to move and speak to students. The device can be connected to ordinary TV sets, already existent in the great majorities of homes, therefore decreasing the overall cost of implementing the solution.

The design process of e-du box is distinct as we explicitly modeled the interface design after analyzing usage in human experience dealing with a low fidelity prototype application. We conducted qualitative field studies to identify teachers and students necessities on constructing and interacting with our prototype. We continually improve the interactions provided to users as we could identify lacking and exceeded features.

In the next section we discuss research and tangible interfaces usage in education. We then present the design of e-du box and the findings of our evaluation of the tools in use. We conclude with discussion of future evolutions of this solution.

2. TANGIBLE INTERFACES IN EDUCATION

Tangible user interfaces (TUIs) seek to change the traditional I/O paradigm of computer systems, creating possibilities of interaction that bring together the digital and physical worlds [18] apud [7] and try to be more natural to human beings. For that purpose, innovative I/O devices are being proposed, in many cases making use of concrete objects of our everyday lives [14].

Zuckerman et al. [20] propose the following classification for TUIs:

1. TUI as input, GUI (graphical user interface) as output: a tangible interface is used as the input device of a computer system, and the output is shown on a screen.
2. Output projected on a TUI: the output of a computer system is not projected on a GUI, but on a tangible interface.
3. Immersive environments: TUIs are interfaces through which users interact with a pervasive computing system.
4. Computing power embedded in physical objects: the TUI works as the input and output devices, with no GUIs involved.

The innovative forms of interaction provided by tangible interfaces make them popular in the Education field. TUIs open new possibilities in didactic practices, extending students’ learning experience [11] by putting together advantages of digital data (like updating capabilities) and physical aspects of tangible resources [13].

Zuckerman et al. [20] also cite some advantages brought by tangible interfaces in Education:

- Sensorial engagement: children learn in natural ways, using different senses (touch, vision, and hearing) in a constructive process which increases retention of learning content.
- Accessibility: tangible interfaces provide more options of interaction to include children with special needs.
- Group learning: with tangible interfaces, discussions and collaborative work are usually encouraged.

In educative systems, the focus is not technology, but the interaction and its effects [10]. Interfaces should direct user attention to the object of the learning activity [7]. If students need to concentrate on how to manipulate the interface instead of thinking of the concept to be studied, learning will probably be less effective [9].

3. DESIGN PROCESS

The development of e-du box was based on the results of a qualitative field research made in Recife, Brazil. The first step was to understand the context of the educational field, identify teachers’ and students’ needs related to literacy and detect opportunities for technology to be used for their benefit. The output from this initial research was key to the ongoing project development efforts. The collected feedback was properly compiled into the guidelines presented in Section 3.2.

We were oriented by a social constructivist framework in our design decisions [1] perceiving reflexive acting and social interaction as part of the origins of human development.

3.1 Participants

We visited schools and interviewed their teachers, coordinators and directors about their teaching practices. We also had informal conversations with specialists from universities, such as pedagogues and psychologists. A positive feedback was given as for the use of technology: both students and teachers became enthusiastic about it. Furthermore, the team received valuable feedback regarding assessments content. Our approach was changed from the learning of letters to exercises which explore the meaning of words in a social context.

Those interactions allowed us to exchange ideas on the conception of e-du box and led us to state some guidelines for the development of the product. We describe those guidelines in the following section.
3.2 Guidelines

1. **Contextual on-demand educative content:** today’s approaches have considerable limitations for educators to add and change educative content related to specific difficulties, preferences and day by day activities of each student. For example, a teacher reported that she attempted to use, in the northeast region of Brazil, educative content (books, exercises, among others) created in the southeast region of the country. However, she was not successful, since such content was based on cultural issues of the southeast region which were not so meaningful to northeast students. Another issue which could be addressed here is the difference among students’ level and abilities in a same class. In Brazil, it is quite common to have students who can read together with illiterate ones. It would be, therefore, very convenient for the teacher to have the possibility of adapting activities for different levels according to the students necessities.

2. **Technology as a mean, not a goal:** as mentioned before, technology is not the focus in educational artifacts, but a mean to improve the learning process. Another point is that teachers must be able to deal with technology and adapt their methods to integrate the new artifacts in class. In Brazil, many teachers are still resistant to use technology, mainly for fear of being unable to manage it in class. In this context, a major requirement is that technology should be easy and simple to set up, use and customize.

3. **Focus on student motivation:** the majority of students’ assessments use pencil and paper as the underlying media. Such fact, combined with the repetitive nature of some assignments, contribute to the loose of motivation. On the other hand, activities that are related to richer media and games (not necessarily digital games) are the ones in which students get more deeply engaged. Hence, the success of future educative approaches requires that they move the student role from static to interactive.

4. **Deeper parental involvement:** schools reported that today’s educational system is still highly dependent on classrooms and the presence of educators. Some pedagogues recognized that many of the exercises assigned to students do not provide the opportunity for a deeper interaction with parents at home or friends outside school. Therefore, learning is not stimulated beyond classrooms. Internet at home still does not solve the problem, since it is not targeted (yet) to the illiterate.

5. **Aided continuous and reflexive assessment process:** the way students’ progress is assessed today is manual and done case by case. This can make the assessment process bureaucratic, repetitive and error-prone. However, we were able to identify that students’ assessment, even in the literacy domain, can be richer and more automated. For example, the traditional student portfolio, which is kept by the teacher to gather all concluded exercises along the year, could be automatically and gradually built once based in digital assessments. Furthermore, digital technologies can make it possible not only to view the result of an assessment solving but also to check each step carried out by the student.

6. **Community reuse:** there is a lack of possibilities to make content creation and sharing by different educators around the world an easy task. In other words, educators have few means to exchange educative assets aided by tool support, efficient searching and automation. One of the reasons is that such assets are not digital, and even if they were, there is no easy way to create and maintain them. However, interviews revealed that teachers would be interested in taking part in online assessment exchange communities to share knowledge and resources.

7. **Articulation with the private initiative:** many successful social projects are carried out and concluded with the collaboration of the private initiative. Some of the interviewed stakeholders believe that literacy is a field where the articulation with the private initiative can arise indeed, especially due to the urgent investments needed to revert current illiteracy statistics.

3.3 E-du Box

With the aforementioned principles in mind, we have conceived the e-du box, a low-cost and flexible hardware/software educational platform. E-du features go beyond literacy purposes, addressing both learners’ personal skills and their understanding about specific concepts. At the same time, it also empowers educators with an interesting tool to build rich (yet localized) assessments situations based on multimedia content, as well as to assess students’ progress in a more automated way.

The high-level platform components are presented in Figure 1.

![Figure 1. High-level e-du box components](image1)

In the client side, the e-du box is a computing device that can be connected to ordinary TV sets, already existent in the great majorities of homes, which would work as the output display. The graphical interface shown on the TV screen resembles a notebook (a traditional one, not the laptop computer) (see Figure 2). The digital notebook layout, such as its cover, can be different for each user. Actually, the whole user interface can be customized.

![Figure 2. Digital notebook interface](image2)
Tabs on the right-hand side of the notebook identify different users. This allows a same device to be used by more than one person (such as siblings in a family or friends in a social community), reducing the overall solution deployment costs.

Once browsing the notebook, students will be faced with assessments and games, each one with rich interactive multimedia experiences, like quizzes, movies, association task, images and spelling. Some of the challenges are multiplayer and engage the involvement of parents and friends, while others can be solved collectively through a connected experience with other students’ e-du boxes. For example, the activity Draw Together suggests an interactive drawing exercise for two students wirelessly connected. They both see the same screen, with a drawing canvas displayed in the center of the right page. The students use the pen-shaped mice as input device for drawing. The students’ drawing colors are displayed differently: one is red, the other is blue (Figure 3).

The activities available for students can be pre-built in the application or deployed on-demand by the educator, through a personal computer (represented by the educator’s computer in Figure 1). Using a Bluetooth connection, educators can synchronize with students’ e-du boxes, collecting information from them, and be aided by a tool called E-ducreator to have on-demand graphics and reports to assess students’ progress automatically. The way a student solved a specific assessment can be reproduced as well. In this way, the educator can monitor the progress of a whole group of students in a centralized and automated fashion.

Once with enough information to define subsequent or corrective learning strategies, educators can develop and deploy to students’ e-du boxes new multimedia interactive exercises. To accomplish that, they can launch a simple yet powerful WYSIWYG authoring tool, called E-ducreator that runs in the educator’s computer, which is used to create lessons. This tool makes it possible to program the input and output capabilities of the e-du box through an intuitive interface. An example is shown in Figure 4. This allows dictations, reading, drawing and many other more advanced school activities to be presented a much more appealing way.

The possibility of updating the students’ application addresses an important requirement identified by educators: the student learning process should not be dissociated from reality and current facts. For example, students should not only be able to read and write the word “war”, but also to understand where and why wars are happening in the world and what is the consequence of such fact to their lives.

Besides deploying the assessment to an e-du box, educators can choose to publish and share their lessons (knowledge and resources) through Shar-e-du, an online educative assessments repository, shown in Figure 5. Items in the repository can be searched by tags in two different ways: from within the authoring tool or through a web portal. Such a repository provides new Web 2.0 capabilities [8] to the edutainment domain, empowering educators with new collaboration and reuse opportunities.

Students are also able to launch the Edupedia (Figure 6), a “learning encyclopedia”, which presents concepts together with related videos, pictures and text, whose complexity level is based on the acquired skills of the student. Concepts related to the current concept are presented through a graph in the left page, inviting the student to explore new content and, consequently, to learn more.
Users interact with the interface by using a pen-shaped mouse [3]. Such experience is intended to be as intuitive and straightforward as the use of a pencil and a sheet of paper, not requiring any previous computer experience or training. However, due to the digital nature of e-du, the interaction level may be much richer than the pencil/paper experience. Moreover, the pen would be equipped with vibrating mechanisms, similar to a force-feedback joystick, in order to better enrich the student interaction.

The client side is also composed by a real, interactive tangible agent, which can be customized. The agent is able to be in motion and speak to students, in order to provide real time feedback and motivate the self-learning process. The communication between the agent and the e-du box is wireless, therefore it can also be moved to any nearby place. A real e-du box usage scenario, with the TV, the e-du box, the pen and the agent, is shown in Figure 7.

4. EVALUATION

A first prototype was developed and brought to schools to be informally evaluated by teachers and students. The focus in this first phase was on the content to be provided to students (e.g., assessments, videos, games), as well as the provided graphical interface. How well students and teachers would accept the technology and deal with it was further investigated. Finally, a “manually operated” version of the interactive agent was presented to teachers, in order to verify the product usability.

A second, higher-fidelity prototype was then developed and more formal tests were made with students. Such an evolved prototype matches the features set described in Section 3.3. The focus was on validating the tangible interface and the platform as a whole. In Section 4.2 we present our analysis of the usability level regarding task effectiveness and learnability.

4.1 Participants and context

Tests were performed in a private school in Recife, Brazil. Students belonged to middle class and were familiar with computers. They were aged 5-6 years and were starting to get to know the alphabet and perform literacy activities.

The prototype was tested using two monitors side by side. Six students took part in the experiment, working in pairs. The experiment scenario is shown in Figure 8.

Figure 8. Experiments scenario

4.2 Activities

In this section, we describe two specific tasks evaluated with users: “memory game” and a “circle the picture” activity.

Memory Test Game: in such a game, two students, using the same computer (eBox) and output display device (a monitor or television), are presented a board with six cards. All cards are turned backwards. The game is played in turns. The first student chooses a card, by clicking on it. The card is flipped and then displays either a word or a drawing. The student’s goal is to find the matching card: if the original card contains a drawing, the matching card contains the word describing that drawing (such as “dog” or “duck”, for example). A point is awarded for each successful matching. In the case of an unsuccessful matching, the selected cards are flipped backwards again. Both student scores are displayed in the left page of the screen. After a student selects his second card in a turn, the other student owes the next turn, no matter if the previous student was successful or not. The students share a same pen-shaped mouse, in turns, as input device. The external agent congratulates the students when a successful match is discovered and says “Not that, try again” when the card pair matching is unsuccessful. Finally, when all cards are flipped, the game ends and the agent congratulates the winner.
Circle picture: in this activity, two students, again using the same computer (eBox) and output display device, are shown some pictures on the screen and are asked to circle the picture whose name starts with a particular letter, also shown on the screen. The students also share a same pen-shaped mouse, in turns, as input device, and have feedback from the tangible agent.

4.3 Data collection and analysis
During evaluation sections, interactions were registered on video for further transcription and qualitative data analysis. A camera was placed behind students capturing their conversation, movements, negotiation protocols and the computer screen display. In this condition, we were able to track the mediation aspects of the interface in the collaborative problem solving situations.

We used collaborative data collection and analysis [6] to obtain accurate results from data faster. In so doing, more interaction design cycles could exist and in consequence more evaluation moments.

5. RESULTS
We present the results of our evaluation through categories derived from the data analysis.

5.1 E-pen is not really a pen
Different from our previous point of view, the pen-shaped mouse is not directly associated to a real pen by students. Students had to be taught how to use the pen as input device, and needed some help to make it work properly. The main problems children faced while interacting with the pen were: holding the pen in such a way that it would touch the table surface and work properly as a mouse; move the pen slowly enough to produce a specific drawing on the screen; synchronize the movement of the pen with the pressing of the buttons to select icons or produce a drawing. However, despite those problems, children were eager to learn how to use the pen and, with that, perform the tasks. During the experiment, some students declared it was quite difficult to circle a picture or make a drawing using the pen, but after some training children said: “I know how to do, it’s easy, it’s easy” and started teaching their mates.

5.2 High tolerance threshold
Despite some technical problems and functional limitations of our prototype, students maintained their engagement during the whole experiment. They were patient and good-humored, showing no negative reactions while waiting to interact with our system.

5.3 Affective aspects in agent-user interaction
Children were involved with the tangible agent, chatting with it (“hello, what’s your name?”), holding its hand, asking permission to touch it and talking about it (“oh! It’s dancing!”). Each time the agent gave some feedback, students looked at it laughing with surprise and joy.

5.4 Captivating interface and activities
Children were motivated and engaged with the interface and activities proposed. They showed interest, pleasure and care while performing the tasks.

6. DESIGN IMPLICATIONS
Reflecting our previous results, we observed some implications in our design process. Two of them are related to the product (6.1 and 6.2) and two others (6.3 and 6.4) with the evaluation methodology.

6.1 Feedback edited by teacher
As situations can be created by teachers, another customization level is related to how the tangible agent can provide movement and audio feedback related to the kind of problem and the level the students are. We could reflect in terms of scaffolding strategies implemented using this part of the interactive system to be closer related to student’s comprehension and involvement in the practice.

6.2 Input tool suitable for young children
When developing a product for young children, we must be very careful when considering the specific input tool. Youngsters may not have developed an accurate motor coordination yet and need a suitable tool for proper and easy interaction. The pen-shaped mouse proved to be a good idea, yet it needs to be improved in order to better react and capture user’s movements.

6.3 Considering aesthetics and affective aspects
We noted obvious aesthetics and affective evidences on the usage of our system by young children. We must include the quality and type of the material used to construct the tangible agent as a variable to understand the relation with user’s reactions and acceptance.

6.4 Understanding interaction as an overall communication process
During the evaluation phase, it is important to understand the overall interaction involving different users in the situation and the teacher previous and asynchronous interaction through the activity planning and distribution and further results collection and evaluation. This complete series of interactions must be conceived to be as continuous as possible in terms of communications over time and inter situations. These considerations have impacted on the way we’ll plan the future observations and data analysis in the evaluation phases.

7. DISCUSSION
Several tangible interfaces have already been proposed for Education. One of them is the Tangible Interface for Collaborative Learning Environments (TICLE) [16], a platform which uses computer vision techniques to track concrete objects and map their movements to personal computers. Children interact with concrete mathematical games (such as Hanoi Tower and tangram [17]) while the system maps their actions to the computer screen, showing their evolution and offering help to guide them towards the solution.

Scarlatos & Scarlatos [17] also developed mathematical mats: SmartStep and FloorMath. The mats have sensors to detect children’s movements on top of them, and are connected to a personal computer which shows a virtual representation of the mat and the activities that should be done by the student. The mats use physical activity to practice math concepts like counting and basic operations.
In Brazil, the educational tables of the company Positivo (www.positivoinformatica.com.br) use concrete didactic materials for children to interact with the personal computer. The activities associated with the tables relate to several knowledge areas and stimulate coordination, visual perception and logical reasoning. Activities are structured according to students’ age and level.

Another example is the I/O Brush [15], a drawing tool in the shape of a common paintbrush, but with an embedded camera and touch sensors. Such devices allow users to capture colors and textures of surfaces and reproduce them on the drawing canvas (consisting of a large touchscreen and a back projection screen).

As for external interactive agents (companions), a lack of solutions targeted at the educative domain was observed. Some currently existent agents actually execute simple actions, such as dancing or blinking when an instant messenger contact becomes online. Other agents are able to pronounce some words and small phrases, but none of them are connected to software systems as part of a broader educative platform.

The products cited above can be classified in the category of “TUI as input, GUI as output” (see Section 2), i.e., input is done through a tangible interface (concrete math games, mats, didactic concrete materials, paintbrush) and output is shown on a separate screen.

As for e-du box, input is done through a special pen and output occurs through three different forms. One of them is the vibration of the pen, which represents a tactile feedback – the pen can therefore be considered an input and output device. Another answer of the system is given through the external agent (a doll) that interacts with the users as a companion to guide them through the activities. Besides being tangible, the companion has a playful aspect, making learning more fun for children and letting them more involved. Finally, the system shows the educational activities on a separate graphical interface (television screen).

Therefore, e-du box goes beyond the approach of “TUI as input, GUI as output”, broadening the range of interactions between the child and the system and providing a richer and more dynamic learning environment.

According to the guidelines presented in Section 3.2, we defined a group of parameters (ranging from 1 to 5) to analyze e-du box and the related products presented in this section. These parameters are: interactivity (INT), connectivity among students (CAS), parental involvement (PIN), audience reach versus cost rate (ACR), personalization (PER), updating capabilities (UCA), openness to external private initiatives (OPI) and community collaboration (CCO). Table 1 presents the results of this analysis.

<table>
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<th>TICLE</th>
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<th>I/Brush</th>
<th>E-du</th>
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Table 1. Comparative analysis: E-du Box and related products

We see that, although E-du Box does not reach the maximum grade (5) in all parameters, it is the product - of the group analyzed - which better addresses the needs we consider important to be satisfied to promote collaborative learning in situ.

Besides those features, educational effect of e-du box involves impacts on a series of individual and group interaction styles, and can also be analyzed according the aspects presented in Section 3.2.

8. FUTURE WORK

The real impact of e-du box in the learning process can be assessed in a long-term basis, by putting the system in use in some classrooms and comparing students’ performance in school with and without it. However, the enthusiasm and interest of students and teachers during the experiments show that there is a good scenario for e-du box to be successful in classrooms.

We believe some features could be added to enhance users’ interaction with e-du box applications: speech and handwriting recognition could make the interaction more natural. Speech recognition could allow children to actually “talk” to the external tangible agent, which could increase their engagement in the activities and make the interaction with the agent richer than pure feedback. Handwriting recognition would allow children to use the pen-shaped mouse in a way closer to the real use of a pen.

Our work could also be easily expanded to cover other content topics than literacy. Mathematics or Science activities, for example, would broaden the range of possible situations of use of e-du box by educators.

We believe e-du box could also be adopted for distance education. Since we already provide interfaces for the educators to create activities, feed students’ equipments with them and collecting results afterwards, changes in the way of communication among users’ equipments and, possibly, adaptations to enhance awareness could make e-du suitable for distance education.

Regarding the cost effectiveness of e-du in developing countries, practical and economic aspects of schools in those countries, such as in Brazil, can be taken into account in order to improve the solution adoption. For example, it is possible to make use of already existent infra-structure scenarios, such as low-cost laptops (as those from the One Laptop Per Child initiative or the Intel Classmate PC) to deploy e-du. Other possibility is to deploy e-du to computers belonging to the donation market scenario, i.e., old computers donated to schools by companies and non-profit organizations. Since the processing power of such machines matches the current platform capabilities (eBox), this would not be a constraint.

Other platforms such as mobile phones, digital TV, and UltraMobile PC could also be explored. However, we believe a careful and deeper analysis of users interaction in each case must be made before actual development of adaptations is performed.
9. CONCLUSION
In this paper, we have presented the design of e-du box - an educational, authoring and sharing multimedia platform including a tangible companion that provides feedback for users. We have also presented a field study which contributed to our understanding of how pupils engage in learning tasks and cooperate in synchronous situation through the interface, besides generating a set of guidelines used in the conception of our product. We could progress in understanding the interactions realized through this interface. We could observe the main interaction possibilities and the main limitations of our concepts and design process.

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